SOLAROLL RADIANT FLOOR HEATING

with funding provided by

Alberta
DEPARTMENT OF HOUSING
Innovative Housing Grants Program

SOLAROLL RADIANT FLOOR HEATING

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Prepared By:

Gilbert M. Rekken and Associates Ltd.
Consulting Engineers

The views and conclusions expressed and the recommendations made in this report are entirely those of the Author's and should not be construed as expressing the opinions of the Alberta Department of Housing.

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FOREWORD

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Innovative Housing Grants Program
Fourth Floor
10050 - 112 Street
Edmonton, Alberta
T5K 2J1

Alberta Department of Housing

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I - INTRODUCTION

A. Objective

The objective of this study was to assess the 'Solaroll' radiant floor heating system. This assessment is based on a radiant heating retrofit in a single family detached bungalow, built in accordance with typical mid-1970's Alberta construction techniques.

B. Heating Philosophy

Residential heating systems have evolved from the centrally located wood stove. A major improvement in comfort and efficiency was achieved when centrally heated air was distributed through the house. The forerunners to the more modern systems distributed the heat by means of gravity.

More modern warm-air heating systems incorporate fans and ductwork to move the air to the perimeter of the house, making up the heat losses where they occur, principally at the windows. This improved heat delivery system does much to solve the problem of "cold spots" common with the earlier systems.

The high cost of energy in the seventies resulted in a trend towards "super insulation" construction practices in order to reduce heat losses from the exterior envelope of the house. In recent times, work has been directed both at the reduction of heat loss from houses and at developing more efficient heating systems.

A highly efficient house has a much reduced need for heat input. This reduction in heating demand requires a review of the criteria for heating systems. The following is a list of criteria for present day heating and ventilation systems:

1. They should provide comfort, minimizing hot/cold air stratification.
2. They should be cost effective (having reasonable capital and operating cost).
3. They must be safe and provide adequate fresh air for safety and long-term health of the occupants.

It should be noted that the criteria apply to both energy efficient and non-energy efficient housing construction.

C. Stratification Versus Comfort

It appears that the house occupants' overall sense of comfort depends to a major extent on floor temperature. This observation derives from common complaints of "cold feet" at even relatively high room temperatures. Diagram No. 1 on page 4 illustrates the reason for this observation. It is the wide variation of temperatures from ceiling to floor produced by the warm-air heating systems. Measurements in dwellings have shown that floor to ceiling temperature gradients can be as high as 13°C (24°F) for the normal (20°C) room thermostat setting. Diagram No. 1 shows that radiant floor heating systems result in relatively warmer floors and cooler air at "breath level" than do warm-air systems. Radiant floor heating systems, with their moderate temperature gradient, result in reduced air stratification and in more comfort.

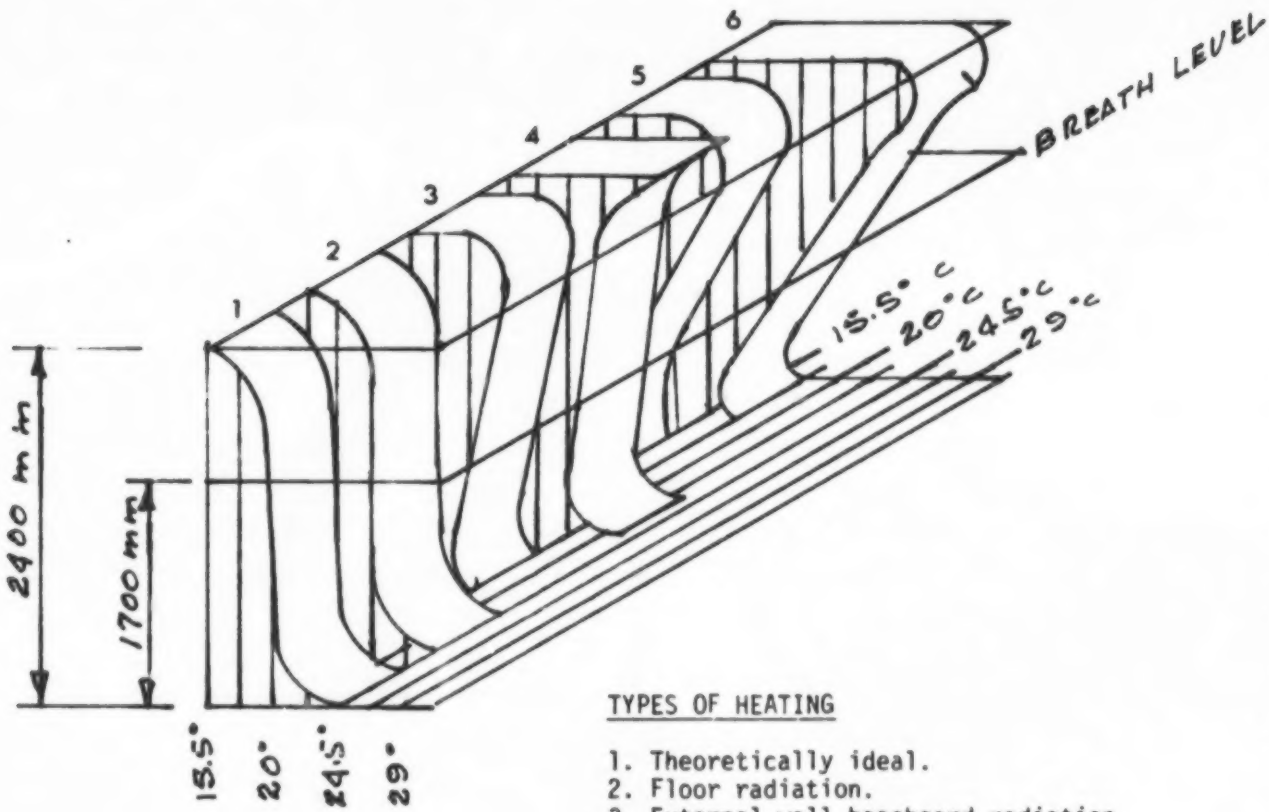
Designers of warm-air systems have recognized that stratification of air is undesirable. However, attempts to overcome the problems of air stratification, usually by increasing the velocity of the air movement

or the rate of air exchange, have not proven totally successful. Too much air movement can be counter productive. It creates drafts at the outlets and can produce high levels of recirculated dust.

From Diagram No. 1 it can be seen that the current standard forced air heating and distribution systems produce the least desirable results, in terms of a floor to ceiling temperature profile. This diagram shows that a floor radiation system most closely conforms to the theoretically ideal heating profile.

DIAGRAM NO. 1

STRATIFICATION CHART FOR VARIOUS HEATING SYSTEMS



TYPES OF HEATING

1. Theoretically ideal.
2. Floor radiation.
3. External wall baseboard radiation.
4. Ceiling radiation.
5. Internal wall radiation.
6. Typical forced air system.

II - RADIANT HEATING SYSTEMS

A. Background

The quantity of heat flow is directly related to the temperature difference between the heat source and the surface receiving the heat. Since the human body temperature (37°C) is always higher than the house temperature (20°C), it is obvious that there will be a constant heat loss from the people to their environment, even on very warm days. It is the rate of body heat loss which determines the occupant's perception of heating* comfort.

B. Heating Methods

Raising room temperatures by radiant heating systems usually involves the use of a combustion appliance, in this case a water boiler, with a complement of secondary radiating devices such as cast iron radiators or baseboard radiators. The water flowing in the pipes serves as the heat transfer medium. The particular location of such radiating devices can be at the perimeter walls or hanging from ceilings or even freestanding within the rooms. All such systems have operated by the principle of radiation from a relatively small surface area. This small surface area has meant that the radiating surface must be relatively hot. Often the ideal room temperature is exceeded near the location of the radiating device while other areas of the room can be too cool.

*Note that temperatures in excess of 21°C require cooling of the house air or air conditioning to produce comfort. Air conditioning or cooling is not dealt with in this report.

Radiant floor heating systems are similar in all respects to the traditional radiant systems except for one important feature. That feature is the heating tubes in the floor which forms one large radiating surface. The benefits of floor radiation result from the large size of the radiant surface.

C. Transfer Mediums

The important properties of a heat transfer medium are its mass and its specific heat, the rate the medium transfers heat. In warm air systems, because air is a low mass medium, a large volume of air must be heated to relatively high temperatures often 50°C or higher. This is necessary to transfer sufficient heat to the air in the house.

Because the specific heat of water is many times higher than air, heat can be moved from its source to required locations using small volumes of water at much lower temperatures.

D. Advantages

Hot water radiant floor heating systems make use of the higher mass of water with its higher specific heat. The potential advantages of hot water radiant floor heating systems compared with the traditional approaches include the following:

1. The large radiant floor area will mean that the system can operate at low water temperatures and give even heat distribution.

2. Radiant heating is very compatible with the trend toward energy-efficient houses which have lower heating requirements; the resulting lower heating demand will mean comfort can be maintained at even lower operating temperatures.

3. Floors and walls are unobstructed by grills and registers.

III - RESIDENTIAL AIR QUALITY

A. Background

Radiant floor heating systems, like all other types of heating systems in a tightly sealed energy efficient house, require fresh air and control of air quality. Contaminants in a closed environment include such substances as formaldehyde, halogenated hydrocarbons, benzene, radon, radioactive gases and a host of personal contaminants including tobacco smoke and dust. These pollutants can vary a great deal in their conflict with human comfort and the long-term effect on human health.* The effects of such conflict may be profound even if they are not readily apparent on the daily basis.

B. Air Exchange

Air quality can be assured only by providing fresh air exchange or air treatment. To date, air treatment has not been found to be economical for residential use. The rate of required air exchange is a function of the number of persons in the house. Additionally, since harmful contaminants are produced constantly, a minimum air exchange rate is required.

The rate of air exchange has been the subject of laboratory study as well as practical tests. Tests done in the 1970's in Sweden have determined that air exchange in the order of 25% to 50% per hour, depending on the 'people-load', is necessary. (See ASHRAE JULY, 1979.) In energy efficent dwellings this air exchange rate becomes a matter of economic concern. Based on the percentage of total heat loss, the cost of heating fresh air required for air quality is considerable, often 50% of the total heat loss, if the heat from the exhausted air is not recovered. Up to 70% of this heat lost through exhausted air can be recovered. The most common means of recovering heat from the exhaust air and to supply adequate fresh air is to install a fan driven air-to-air heat exchanger.

*See the MAY 1983 issue of ASHRAE-environmental quality for additional information on air contamination and health concerns.

For health reasons, a fan driven air supply/exhaust system (to supply the required fresh air) should be provided for all energy efficient houses.* Heat recovery, through the use of an air-to-air heat exchanger is optional.

C. Humidity

Humidity levels involve trade-offs. Too high humidity levels can cause damage to building materials. Too low humidity levels result in occupant discomfort. It has been found that the relative humidity of the room air should be maintained between 35% and 55% - a good balance between the people and building requirements. An advantage with radiant hot water systems is that they tend to maintain higher humidity levels than warm air systems.**

* The demonstration house was not tightly constructed and not energy efficient. A separate air supply/exhaust system was not provided.

**In very air-tight houses, the relative humidity may actually get too high and then there would be no advantage to this feature.

IV - RETROFIT DEMONSTRATION

A. Description

A conventional house was retrofitted to demonstrate and assess a radiant floor heating system. The house* was a non energy-efficient 165 m2 (1800 s.f.) bungalow with standard 38 x 89, RSI 2.1 (2x4, R12) exterior stud walls, with RSI 3.5 (R20) ceilings and with a standard polyethelene, trade installed air/vapour barrier. The building design and window orientation did not take into account energy conservation or solar gains. The original heating system consisted of two warm air, gas fired furnaces with standard ducting accessories and controls. Photographs of the retrofitted house are shown on page 25.

B. Design Considerations

The house had a calculated maximum heat loss of 33.4 kW (114 MBH)** based on standard design methods and the usual 55°C total design temperature difference for the Edmonton area. One air change per hour was assumed in the heat loss calculation.

The house had been heated by the two warm air furnaces until November 1982 when the retrofit conversion was made. The upper furnace was a 65 kW (225 MBH) and the lower floor (basement) furnace was a 36 kW (125 MBH). The total heating input capacity of the system was 101 kW (350 MBH) plus the capacity of the domestic hot water system. Before conversion, considerably more input capacity had been provided than required, probably due to over-conservative furnace selection by the installer. The heating system had worked adequately except for its relatively high operating costs and the system's inability to maintain comfortable temperatures in the living room. The living room was 400 mm lower than the main floor level and for this reason collected cold air which was a source of considerable discomfort to the owner.

* Location of the house: Eastwood Estates, Ardrossan.
** KW - kilowatt, MBH - Thousand British Thermal Units per hour.

C. Heating Record

Energy demand for the test house was measured over the period October 21, 1980 to October 20, 1982 before the changeover and the period after the changeover from January 21, 1983 to March, 1984.

The chart on page 12 shows the energy consumption of the test house. During the retrofit additional energy demand was added by the addition of a small sun room to the end of the living room and a supplemental gas heater to the garage. Both were added in November 1982. For a normal year, the degree days would be approximately 5500. From the graph on page 13, it can be projected that the energy consumption before and after retrofit conversion would be approximately 270 and 220 gigajoules (GJ), respectively, for a normal year.

The extra load imposed by the garage has been calculated at a minimum of 25% of the heating load for the house. Therefore, the savings in energy consumption due to the retrofit is calculated as follows:

Apparent savings from utility bills = 50GJ
Plus heat contributed to garage @ 25% (220GJ) = 55GJ
Total Savings 105GJ
or $\frac{105}{270}$ = 0.389, or approximately 39%

D. Heating Load

Under design conditions, the gas demand includes provision for:
(a) Thermal conducted losses (HLc);
(b) Replacement air heating due to infiltration (HLi);
(c) Domestic hot water demand.

For the demonstration house at design conditions the division is as follows:

(a) HLc (Conducted)	20.8 kW (62.2%);
(b) HLi (Infiltration)	12.5 kW (37.8%); and
(c) Estimated domestic hot water	14 kWh/day constant.

While the domestic hot water demand is constant year-round, the HLc (conducted) and HLi (infiltration) heat losses are variable depending mainly on the temperature difference between inside and outside, and also on other environmental conditions such as wind speed and direction.

E. Energy Consumption - Historical Data Chart

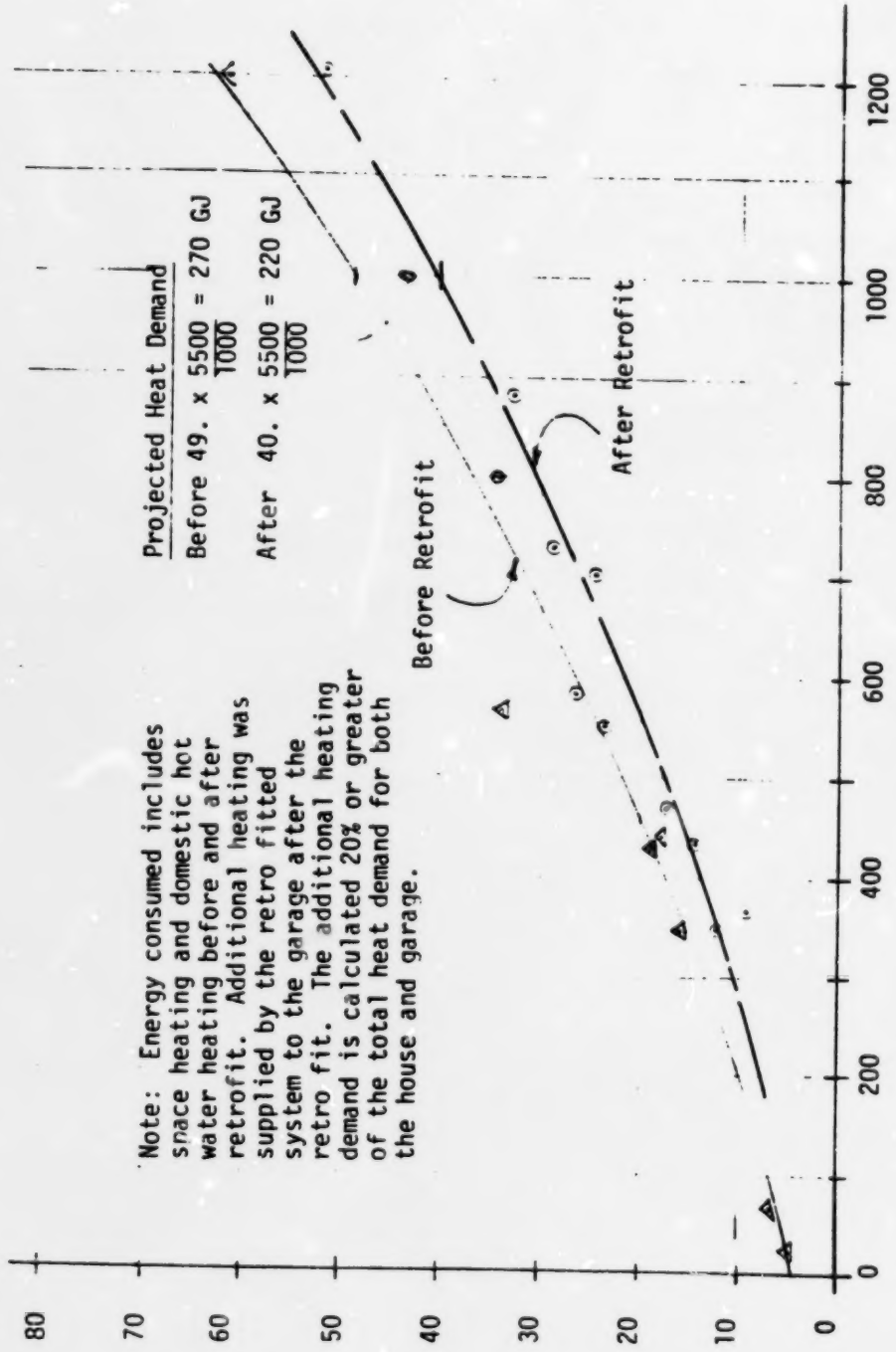
Pt.	GJ	DDC	Time Period	No. Days	Remarks
1	196.2	3816	Oct. 21/80 - Apr. 21/81	183	Not shown on graph
2	16.1	346	Apr. 22/81 - June 18/81	58	
3	7.1	68	June 19/81 - July 21/81	33	
4	5.0	27	July 22/81 - Aug. 20/81	30	
5	19.0	432	Aug. 21/81 - Oct. 21/81	62	
6	61.5	1200	Oct. 22/81 - Dec. 21/81	61	
7	195.8	3475	Dec. 22/81 - Apr. 20/82	120	Not shown on graph
8	17.5	446	Apr. 21/82 - June 18/82	59	
9	33.6	568	June 19/82 - Oct. 20/82	124	
10*	85.5	1401	Oct. 21/82 - Dec. 20/82	61	Heating Retrofit Occured
11	-	-	Dec. 21/83 - Jan 20/84	31	Heating record unavailable
12	32	885	Jan. 21/83 - Feb. 18/83	28	
13	29	726	Feb. 19/83 - Mar. 22/83	32	
14	18	484	Mar. 23/83 - Apr. 22/83	31	
15	14	445	Apr. 22/83 - June 20/83	60	
16	12	348	June 21/83 - Aug 21/83	62	
17	9	373	Sept. 21/83 - Oct. 21/83	30	
18	24	548	Oct. 22/83 - Nov. 22/83	32	
19	34	804	Nov. 22/83 - Dec. 16/83	25	
20	52	1211	Dec. 17/83 - Jan 23/84	38	
21	28	575	Jan. 24/84 - Feb. 20/84	28	
22	24	701	Feb. 21/84 - March 21/84	30	

GJ - Heat consumed in Gigajoules
DDC - Degree days Celsius

* - The following additional loads were added during the retrofit:
1. Sunroom - Nov. 1982.
2. Garage Heater - Nov. 1982.

DIAGRAM NO. 2

Graph of Energy Consumption



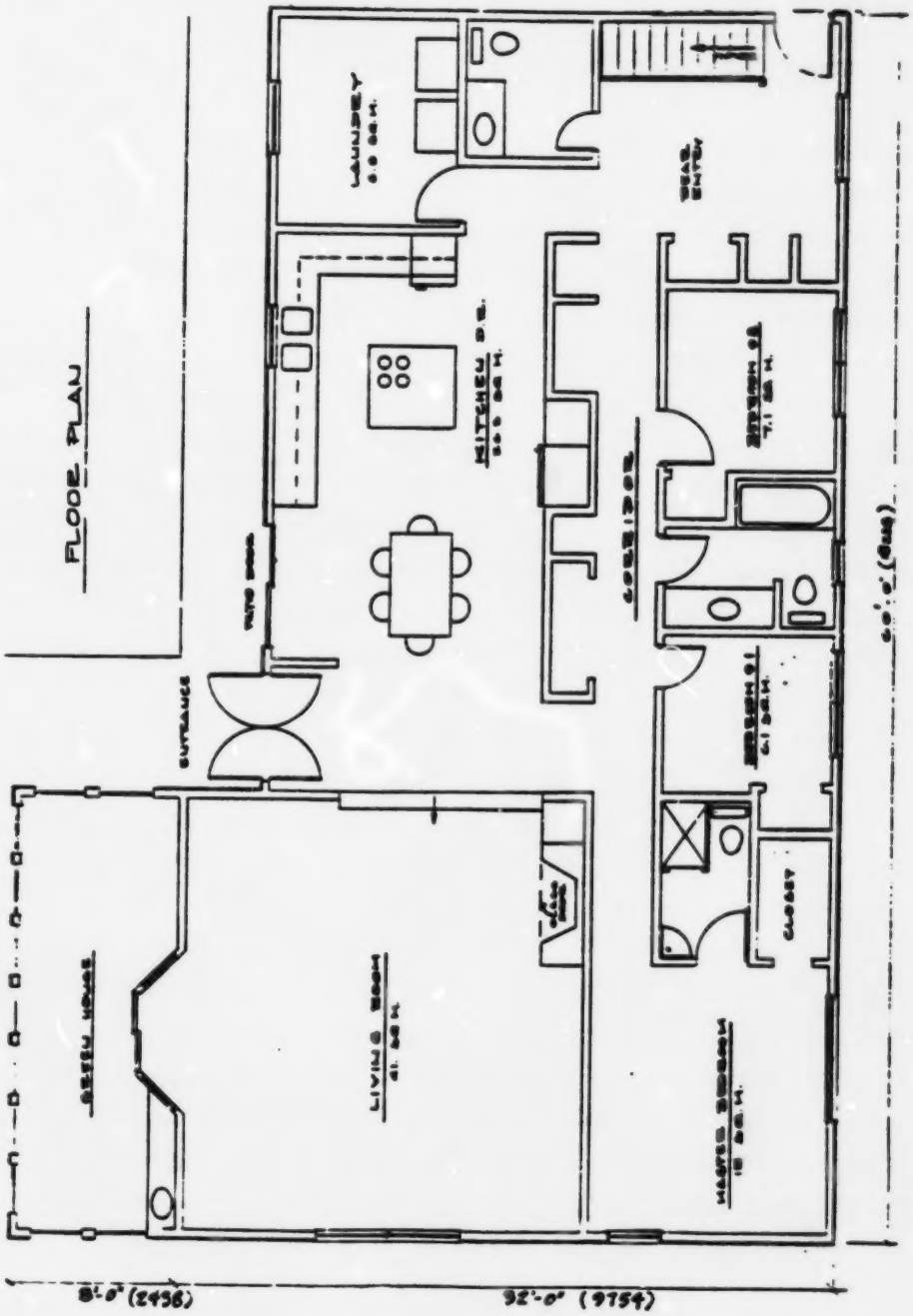
F. Radiant Floor Heating Retrofit

The floor plan of the retrofitted demonstration house is shown as Diagram No. 3 on page 15. The heating zones of the house are shown on Diagram No. 4, page 17. As previously noted, some modifications were carried out in the winter season of 1982/1983, namely the installation of a garage heater and the addition of a sun room to the living room. This sun room is not taken into consideration in the heating demand calculations due to its predominantly south orientation and an initial assessment which indicated that its contribution to the net total demand was not significant. Radiant floor heating was also installed in this addition at the same time as the house was converted to the radiant floor heating system.

The radiant heating system installed in the demonstration house consists of a high efficiency gas burning boiler which heats the water. The heated water is delivered by several individually controlled headers, or main heating pipes. The system is divided into six heating zones. Conversion from the forced air system to radiant heating system was accomplished by working from the basement level. The main floor furnace and the main warm air heating ducts were removed. The small basement counterflow furnace and related ductwork was left in as a standby system for the basement area.

DIAGRAM NO. 3

RESIDENCE FLOOR PLAN



V - DESIGN OF THE RADIANT SYSTEM

A. Layout of the Radiant Grid

Radiant tubing was placed above the floor and encased by a topping of 30 mm of "gypcrete", a type of cement topping. Diagram No. 4 on page 17 shows the general arrangement of the radiant tubes. In general, it is more economical to install the radiant tubing under the subfloor. However this arrangement was not considered practical due to the pre-existing finished ceilings in the basement area.

The radiant system consists of a grid of 5 mm inside diameter tubing of a synthetic elastomer material EPDM (Ethylene-Propylene Diene Monomer). The characteristics of this tubing material are high resistance to chemical or oxidation breakdown and a thermally functional temperature range of -51°C to +190°C. The tubing material is also highly resistant to snags and abrasions and it has a long record of maintaining its resiliency. The radiant tubing material was taped to the floor and embedded in gypcrete, the self-levelling cement topping. The installation crew was impressed by the speed and ease with which the tubing could be installed. The engineering data and the design method used for the spacing of the tubes, to achieve the desired heating response, is shown on pages 19 and 20.

The boiler in this case was a Hydro- Pulse with 29.3 kW (100 MBH) heating input capacity and a rated seasonal efficiency of 90%.* In this installation, the radiant tubing was installed in pairs and spaced at 225 to 300 mm. The design flow rate per tube is 0.0126 L/s at a boiler temperature of 54°C. The floor area was divided into the six heat zones shown in Diagram 4, page 17. The arrangement of the components making up the system is shown as Diagram No. 5 on page 18.

*Other boilers such as a VEISSMAN, would have been adequate (with a rated seasonal efficiency between 80% and 90%) and would have been less expensive.

DIAGRAM NO. 4

LAYOUT PLAN OF RADIANT SYSTEM

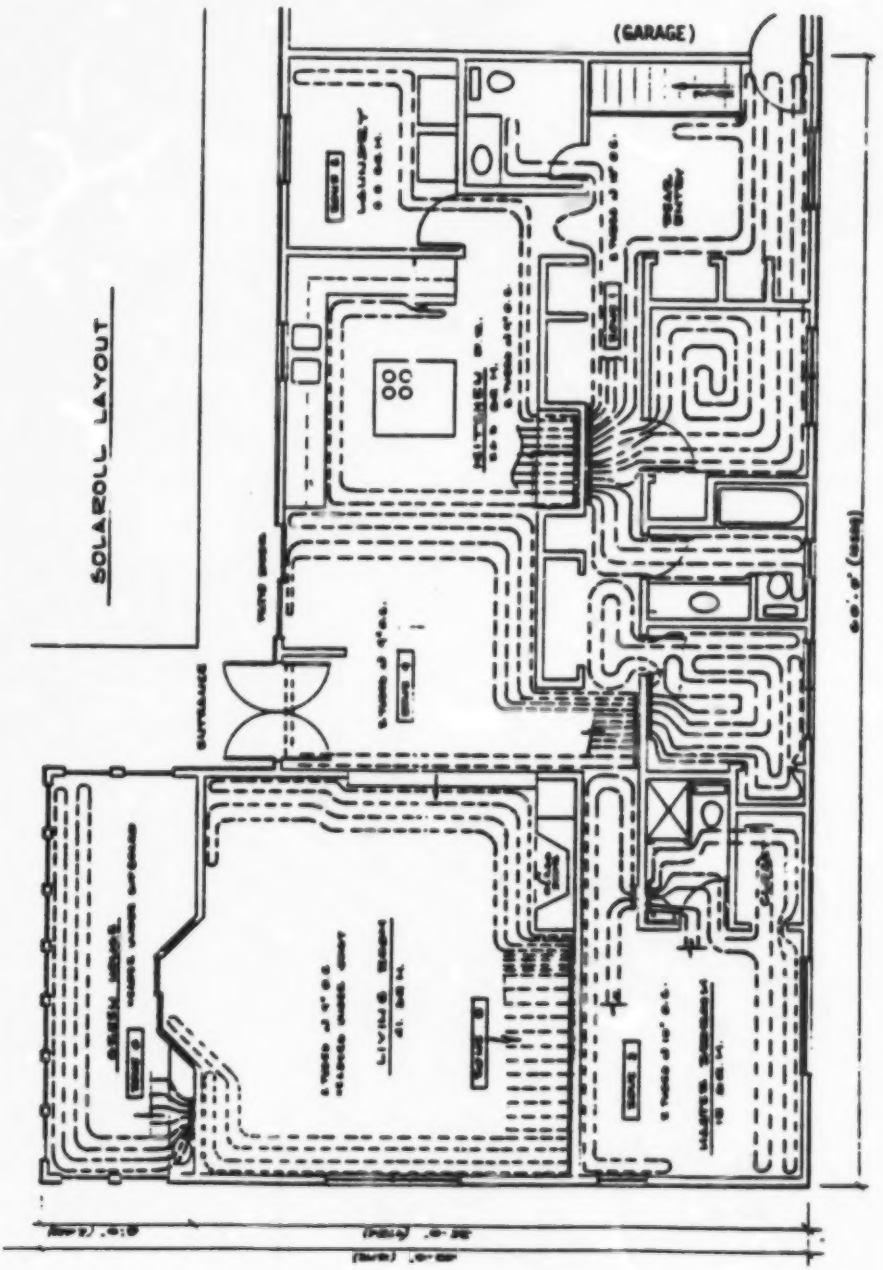
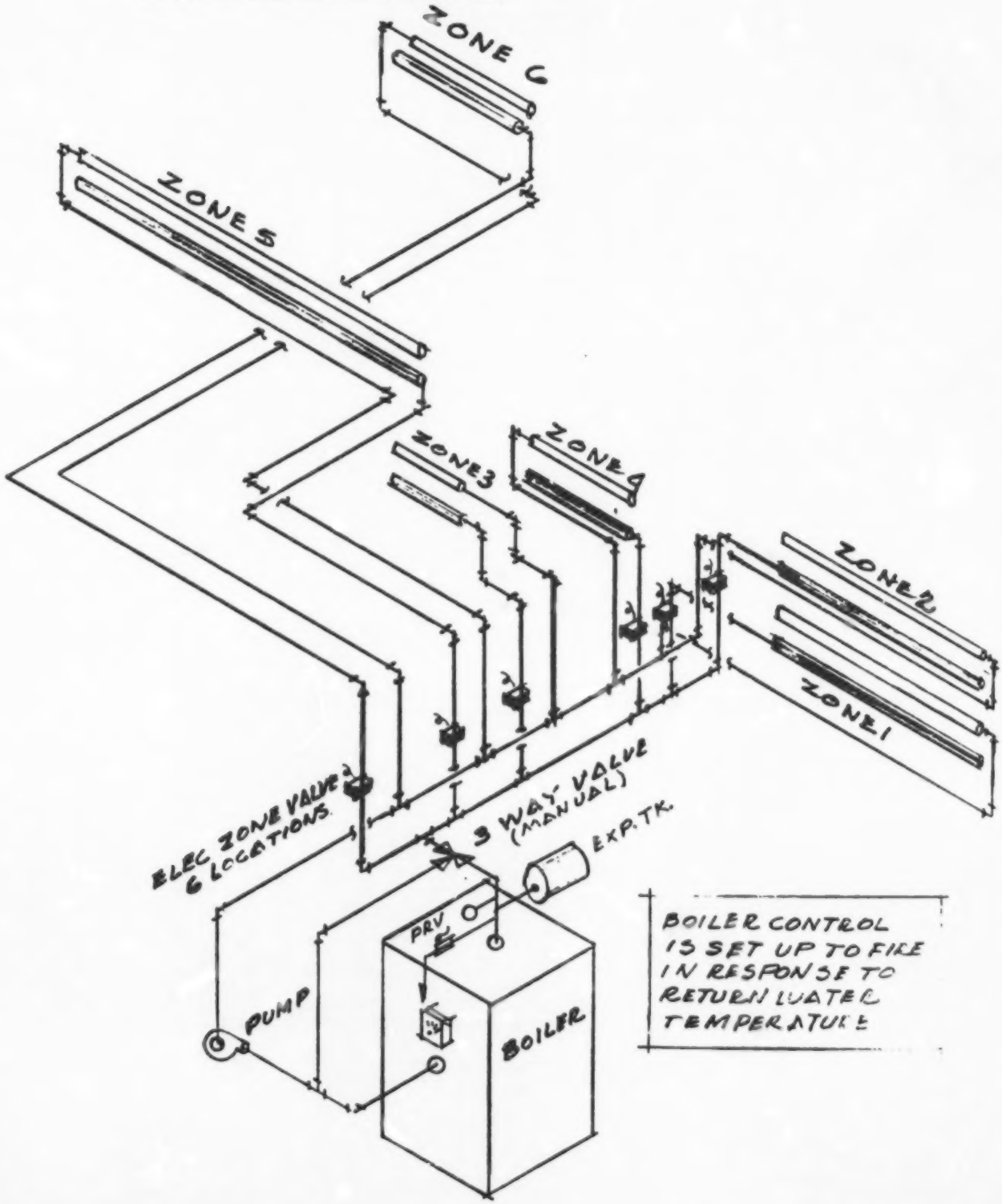


DIAGRAM NO. 5

SCHEMATIC PLAN OF HEATING SYSTEM



B. Design Data

NAME	Tindall Residence				
	ARDROSSAN, Alberta				
WEATHER DATA	Edmonton, Alberta				
ENERGY COSTS	Natural Gas	$0.11m^3$	= $ 2.94/GJ		
	Electricity	$0.38/kWh	= $10.53/GJ		
	Propane	$0.18/L	= $ 7.14/GJ		
TEMPERATURE GRADIENTS	Inside	20°C	±2°C		
	Outside	-35°C			
	Basement	19°C	±3°C		
LEVEL OF THERMAL MASS	13 mm gypsum board wall and ceilings Carpet over 38 mm gypcrete floors				
AIR EXCHANGE FACTORS	Uncontrolled ventilation 0 - 15 km/h - 0.5 AC/Hour 15 - 75 km/h - 1.0 AC/Hour				
INTERNAL HEAT GAIN FACTORS	(a) Daily electrical consumption			14	kWh/day
	(b) Daily domestic water heating consumption			14	kWh/day
	(c) Heat value of occupants - typically			3.5	kWh/day
CALCULATED TRANSMISSION LOSSES	Roof and ceilings		600 W	2.041	MBH
	Walls above basement		3487 W	11.9	MBH
	Windows and doors		6616 W	22.57	MBH
	Basement above grade		1840 W	6.27	MBH
	Basement below grade		3640 W	12.42	MBH
	Basement floor		4663 W	15.9	MBH
	TOTAL HEAT LOSS CONDUCTED		20.8 kW	71	MBH
CALCULATED INFILTRATION LOSSES	Upper Floor	0-15 km/h	4307 W	(14.7	MBH)
	Upper Floor	15-75 km/h	8614 W	(29.4	MBH)
	Basement		3927 W	(13.4	MBH)
TOTAL HEAT LOSSES	Winds	0-15 km/h	29.0 kW	(99.1	MBH)
	Winds	15-75 km/h	33.4 kW	(114.0	MBH)
	Upper Floor-Total losses		19.4 kW	(66.0	MBH)
	Lower Floor-Total losses		14.0 kW	(48.0	MBH)
	TOTAL		33.4 kW		

C. Boiler Sizing

Total upper floor demand 19.4 KW (66.0 MBH)

Boiler required = $\frac{\text{Heating demand}}{\text{Boiler efficiency}}$ X Reserve

$= \frac{19.4 \text{ KW}}{0.9^*} = 21.6$ KW (73.5 MBH)

Boiler size available is 29.3 KW (100 MBH); Reserve = 1.36

D. Typical Room Layout

(Using Master Bedroom as an example)

Room Heat Loss .....2340 Watts (8.0 MBH)

Heat delivered in water = Weight of water x temperature difference

Water delivered per tube is 0.0126 L/s(0.166 GPM)

Temperature drop 9°C (16.4°F)

Heat conducted per tube = 0.0126 L/s x 4187 J/L/°C x 9°C = 475 Watts
(1 Litre x 1°C = 4187 Joules)

No. of tubes required = $\frac{2340}{475} = 4.9$ - Use 5 tubes

Imperial Calculation: (1 lb. of water x 1°F = 1 BTU)
Heat delivered per tube

= 0.166 G/M x 10#/G x 60 M/H x 16.4°F = 1.632 MBH

= No. of tubes required = $\frac{8.0 \text{ MBH}}{1.632}$ 4.9 = Use 5 tubes

See Diagram No. 4 - 5 loops are provided

NOTE: Tubes are evenly spaced over the floor area in equal lengths per loop running away from the header and return, (2 passes).

Room width is 3000 mm, therefore, spacing is:

$\frac{3000 \text{ mm}}{5 \times 2} = 300$ mm

*0.9 is manufacturer's rated efficiency

E. Retrofit Performance Data*

DATE	TEMPERATURE (°C)			
	OUTSIDE	THERMOSTAT SETTING	FLOOR	CEILING
Dec.	-26	20	24	21
Dec.	-20	20	23	22
Dec.	-16	20	21	22
Jan.	-18	20	22	22
Jan.	- 2	20	20	22
Jan.	-22	20	21	21
Feb.	1	20	20	21
Feb.	5	20	24	24
Feb.	-13	20	21	22
Mar.	- 6	20	22	22
Mar.	0	20	22	24
Mar.	4	20	23	22

Readings were taken on the same 3 days of each month and the temperatures, both near the floor and near the ceiling, were recorded while thermostat was set at 20°C. The floor temperature varied slightly depending on whether or not the zone was operating. Humidity was held steady between 40-50% and recorded with an Airguide Model #605 Humidity indicator.

*Data collected by occupants, December, 1982 to March, 1983.

VI - COSTS

A. Retrofit Costs

The costs of the demonstration retrofit, radiant heating system were not typical due to several factors. These factors include the shape, large size, low levels of insulation, and leaky nature of the demonstration house. The cost* of components making up the retrofit radiant floor heating system can be summarized as follows:

Supply and install VEISSMAN** boiler	$1,575
Supply and install pump accessories, zone valves, thermostats c/w fittings	1,115
Supply and install 1,100 lin. ft. of Solaroll radiant tubing @ $2.00 per lin. ft.	2,334
Supply and install copper header line and Solaroll inserts	400
Supply and install 165 s.m. of gypcrete	2,000
Cost of retrofit floor heating system**	$7,424

To compare a retrofit installation with new construction is not possible. An approximate cost can be determined on a hypothetical basis. The following table takes many of the unit costs from the retrofit experience and compares two equivalent hypothetical systems. The compared systems are a radiant floor heating system and a forced air system both of which are suitable for a modest (100m to 110m) bungalow designed to energy-efficient, air-tight standards. The costs shown in the table on page 23 indicate that the radiant floor heating system, for this typical bungalow, would be approximately $1,500 to $2,000 higher than the cost of a forced air system.

* Does not include cost of removal and replacement of carpeting and removal and replacement of doors, base, etc.

**VEISSMAN boiler costs are representative of this type of boiler.

B. Hypothetical Cost Comparisons - Radiant VS. Forced Air (Energy-Efficient Houses)

1. Radiant Floor Heating System (all prices are supply and install):

Boiler	$1,500	
Controls and valves	500	
Solaroll	1,100	
Insulation and foil	400	
Header piping and connections	300	
Fresh air system including AAHE*	1,500	
Miscellaneous	200	
Total Installation Cost		$5,500

2. Conventional Forced Air System:

Energy-efficient furnace	$1,200	
Ducting	1,000	
Fresh air system including AAHE	1,500	
Miscellaneous	100	
Total Installation Cost		$3,800

Incremental or extra cost of radiant floor heating system: $1,700.

C. Energy Savings and Payback

The savings in operating costs for the retrofitted house is estimated at $261 (105GJ @ $2.49 per GJ) or a 39% savings over the cost of heating the house before retrofitting. The capital cost of the retrofit has a simple payback in energy savings of 28 years ($7424/$261 per year).

* AAHE - air-to-air heat exchanger

The savings in operating costs for the hypothetical energy-efficient house could also be expected to be approximately 39%. In Edmonton, the space heating demand for an energy-efficient bungalow (based on energy consumption of "R-2000" + 50%)* would be less than 60GJ at a cost of approximately $150.00 per year. Savings would be approximately $59 per year. Simple payback would be about 30 years. Strictly on a payback basis, a period greater than 10 years is not considered economic.

* R-2000 is the name given to the Federal Energy, Mines and Resources "super-energy efficient house" standard.

PHOTOGRAPHS OF RETROFITTED HOUSE

SOUTH ELEVATION

NORTH ELEVATION

PART VII

SUMMARY AND CONCLUSIONS

A. General Observations

This report points out certain advantages to the concept of using floors for heat radiation. In this practical case study, the house occupants' main requirement for more comfort within the house was indeed accomplished. After the retrofit, the occupants report that they are comfortable even in the sunken living room area, demonstrating the effectiveness of their radiant heat distribution system.

B. Advantages

Building scientists have established that temperature differences are the main driving force for heat loss. Radiant floor heating systems have a near ideal temperature distribution with higher floor and lower ceiling temperatures compared with warm air systems. Maintaining lower ceiling temperatures will reduce heat losses through the roof and upper walls, resulting in more economical operation. Increased comfort is afforded by the warmer air at the floor (foot level) and cooler air near the ceiling (breathing level).

The advantage of this reversal of the usual heat distribution, although mainly qualitative at this time, is apparent - radiant floor heating systems offer more even heat distribution; stratification of heated air is minimized; and it is easier to maintain house air at higher relative humidity. Radiant floor heating can offer both superior performance and a more comfortable house environment.

C. Disadvantages

Installation of a radiant floor heating system is not yet considered standard trade practice and some training is required before installers can make the many connections and install the other special features. This training and familiarization requirement exists for all new technology and installation will seem less complex to the trades as the system becomes more common. The fact that radiant floor heating systems are in their developmental stages in Alberta probably overstates, at this time, the cost disadvantage compared to the common forced air system. However, "the bottom line" is that radiant floor heating systems are presently more expensive than forced air systems.

Another disadvantage of the demonstration system is the possible lack of adequate air circulation because the house does not have a separate mechanical ventilation system. The trend in the building industry is towards energy efficient, tighter house construction. A separate fresh air system is becoming common practice for energy efficient homes with all types of heating systems. Such a fresh air system would also ensure adequate air circulation for radiant floor heating systems.

D. Conclusion

It is evident that radiant floor heating, hot water systems can meet the major criteria of a present day heating system. Radiant floor heating can provide near ideal comfort by minimizing hot/cold stratification while offering potentially lower operating costs.

It is difficult to predict the exact costs of a new installation when such costs are based on this retrofit demonstration house. It is felt that, for an energy efficient bungalow of the usual floor area 110 m^2 (1200 sq. ft.), the present incremental cost for a radiant floor heating system would be $1700 more than the forced air system. Although this extra cost is too high to be considered practical for modest housing, the following four points should be borne in mind:

1. The extra cost of the radiant floor heating system should tend to decrease as the installations become more common.

2. The extra measure of comfort could be considered extra value, thereby offsetting at least part of this extra cost.

3. The radiant floor heating system, with its low water temperature requirement and its large radiant floor area, would be ideally compatible with an active solar, hot water collector system.

4. The operating costs of hot water radiant floor heating systems can be expected to be lower than the operating costs of typical warm air systems. Lower operating costs are the result of three factors: higher boiler efficiencies (80% to 90% vs. 75% for medium-efficiency warm air furnaces), more moderate operating temperatures and reduction in undesireable air stratification. In the case of the radiant floor retrofit, the seasonal operating costs for the house were reduced approximately 39%.

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